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ABSTRACT

Exposure spectra at a distance of 1 meter from the NBS vertical-beam ^{60}Co gamma-ray source are presented in tabular form for field sizes of practical interest. Included are total exposure spectra as well as a breakdown of the scatter contribution according to its origin in the source proper and in the source housing and collimator.

1. Introduction

As a part of a long-range program of providing adequate characterization of the x- and gamma-ray beams employed in the instrument-calibration program of the National Bureau of Standards (NBS), measurements were made of the spectrum in one of the ^{60}Co gamma-ray beams used in this program. Procedures for arriving at spectral distributions from the experimental pulse-height distributions obtained at two distances from the source, and for isolating the spectra due to scatter from the source proper and from the housing and collimator were reported elsewhere [1]. In practical applications to instrument calibration, one usually is interested not in the number of scattered photons in a particular photon-energy interval but in the contribution of these photons to the total exposure -- information that can be derived readily from the photon spectra. It is the purpose of this report to present, in tabular form, such exposure spectra for the scattered radiation below 0.80 MeV, at a distance of 1 meter from the NBS vertical-beam ^{60}Co gamma-ray source, for collimator apertures of practical interest.

2. Method for deriving the exposure spectra for different collimator apertures

2.1 Deriving exposure spectra from number-of-photon spectra

Following the notation in the original paper [1], let s_j be the number of scattered photons in the jth photon-energy interval of width 0.05 MeV. Expressed in percent of the total number of photons, N, reaching the detector, the number of photons in the jth interval then is $100\ s_j/N$. Similarly, at the location of the detector, let x_j be the exposure due to scattered photons in the jth energy interval. Expressed in percent of the total exposure, X, at the detector, the exposure due to scattered photons in the jth interval then is

$$100\ x_j/X \equiv 100\ s_j E_j \mu_{en}^{air}(E_j)\ /\ X,$$

where E_j is the average photon energy, in the jth interval, $\mu_{en}^{air}(E_j)$ is the corresponding mass energy-absorption coefficient of air [2], and the total exposure, X, is given by

$$X \equiv \sum_{j=1}^{n} s_j E_j\ \mu_{en}^{air}(E_j) + \frac{1}{2}\ (N - \sum_{j=1}^{n}\ s_j)[E_{1.17}\mu_{en}^{air}(1.17\ \text{MeV}) + E_{1.33}\mu_{en}^{air}(1.33\ \text{MeV})].$$

In this expression, the sums are extended in equal 0.05-MeV intervals from 0.10 to 1.00 MeV while, above 1.0 MeV, where the data for the spectra of the scattered photons were rather poor, only two intervals are considered, namely, 1.00 to 1.17 MeV and 1.17 to 1.33 MeV. The data below 0.10 MeV, which may have been spurious, are excluded, since, according to results obtained with Monte Carlo methods, the number of scattered photons below 0.10 MeV to be expected in this source geometry is negligibly small [3]. Converting number of photons to exposure makes a possible contribution below 0.10 MeV even smaller, since it takes about five photons of an energy between 0.03 and 0.10 MeV to make the same contribution to exposure as one unscattered ^{60}Co photon.

Because of experimental evidence that the scatter contribution -- beyond a certain lower distance limit -- changes only slowly with distance from the source [1], it is justified to take the experimental scatter spectra obtained at a distance of 1.08 m to be identical, for all practical purposes, with scatter spectra at a distance of 1.00 m.

To obtain the effect of a variation in field size on the contribution of scattered photons to exposure, the following expression was used:

$$\frac{100}{X^{(1)}}\left(x_j^{(1)} - x_j^{(2)}\right) \equiv \left(\frac{100x_j^{(1)}}{X^{(1)}}\right) - \left(\frac{X^{(2)}}{X^{(1)}}\right)\left(\frac{100x_j^{(2)}}{X^{(2)}}\right),$$

where $100(x_j^{(1)} - x_j^{(2)})/X^{(1)}$ is the difference between the contribution of scattered photons to exposure for the larger field size (superscript 1) and the corresponding contribution for the smaller field size (superscript 2) expressed in percent of total exposure for the larger field size; $100\ x_j^{(1)}/X^{(1)}$ and $100\ x_j^{(2)}/X^{(2)}$ are the percent contributions to exposure in the jth energy interval obtained from the measured number spectra for the two field sizes; and $X^{(1)}$ and $X^{(2)}$ are the values for the corresponding total exposure for the two fields obtained from ionization measurements.

2.2 Deriving exposure spectra for the field sizes of interest.

The exposure spectra were computed from the measured number spectra [1] as outlined, and smooth curves were drawn of exposure contribution in each energy interval as a function of field size used in the measurements. The exposure contribution for the field sizes and the distance of interest were determined by interpolation of these curves. No interpolation was attempted for the rectangular field.

3. Results

The results are presented in tables 1 and 2. The scatter contribution to exposure above 0.80 MeV, which, depending on field size, was between 1 and 5 percent, was not tabulated separately, but was added to the exposure contribution due to unscattered photons in the 1.17- and 1.33-MeV lines. This was done because the original data were poor for energies in the vicinity of the unscattered photons, and did not lend themselves to interpolation. This shortcoming should not influence the practical usefulness of the presented data, since, in this energy region, the response of most instruments submitted for calibration does not appreciably depend on photon energy.

In table 1, contribution to exposure is shown per energy interval, in percent of the total exposure at a distance of 1 m, for the different field sizes. Also listed at the bottom for each field size is the exposure contribution below 0.80 MeV, in percent of the total exposure. This contribution is entirely due to scattered photons. The uncertainty attached to its value represents one standard deviation, compounded from the statistical error in the count rate, the unfolding error, and the goodness of fit between the unfolded spectra and the measured pulse-height distributions [4]. Not included are the comparatively small systematic errors, e.g., those due to limitations in the knowledge of the absorption coefficients. For simplicity's sake, no uncertainties are shown for the scatter contributions in the individual energy intervals. These uncertainties vary from interval to interval, being worst at the very low and the very high energies. For the uncertainties in each interval, the reader is referred to the photon spectra shown in figs. 6 through 8 of the original paper [1], in which error bars are plotted for each point.

While table 1 shows exposure spectra including scatter from the source proper, the housing, and the collimator, table 2 shows the scatter contribution from the housing and collimator alone, (for different field sizes), and from the source alone. Also shown, for representative field sizes, are the increases in the scatter contributions due to increases in field sizes. These latter contributions are expressed in percent of the values of exposure obtained with the larger of the two listed field sizes.

Table 1. Exposure in consecutive energy intervals for different field sizes. The values are expressed in percent of total exposure at a distance of 1.0 m.

ΔE(MeV)	Percent Exposure in Energy Interval ΔE for Field Sizes:					
	5 cm x 5 cm	10 cm x 10 cm	15 cm x 15 cm	20 cm x 20 cm	25 cm x 25 cm	6.25 cm x 31.25 cm
0.10 - 0.15	0.03 %	0.04 %	0.04 %	0.05 %	0.05 %	0.04 %
0.15 - 0.20	0.08	0.10	0.10	0.10	0.10	0.09
0.20 - 0.25	0.22	0.25	0.25	0.25	0.25	0.23
0.25 - 0.30	0.36	0.44	0.44	0.45	0.45	0.42
0.30 - 0.35	0.43	0.55	0.56	0.56	0.56	0.52
0.35 - 0.40	0.49	0.66	0.68	0.69	0.69	0.62
0.40 - 0.45	0.51	0.73	0.78	0.79	0.80	0.68
0.45 - 0.50	0.47	0.71	0.76	0.77	0.78	0.65
0.50 - 0.55	0.39	0.60	0.65	0.66	0.67	0.56
0.55 - 0.60	0.29	0.46	0.51	0.53	0.53	0.44
0.60 - 0.65	0.23	0.38	0.42	0.44	0.45	0.36
0.65 - 0.70	0.23	0.36	0.41	0.43	0.44	0.33
0.70 - 0.75	0.22	0.35	0.39	0.42	0.44	0.32
0.75 - 0.80	0.18	0.31	0.36	0.39	0.41	0.29
0.80 - 1.33	95.9 %	94.1 %	93.6 %	93.5 %	93.4 %	94.5 %
$\sum_{0.10}^{0.80}$	4.1 ± 0.7 %	5.9 ± 0.3 %	6.4 ± 0.7 %	6.5 ± 0.7 %	6.6 ± 0.6 %	5.5 ± 0.7%

Table 2. Exposure in consecutive energy intervals below 0.80 MeV, from scatter due to the housing and collimator, and due to the source proper. The values are expressed in percent of total exposure at a distance of 1.0 m.

ΔE(MeV)	Percent Exposure in Energy Interval ΔE Due to Scatter by Housing and Collimator, for Field Sizes:		
	6.25 cm x 6.25 cm	12.5 cm x 12.5 cm	31.25 cm x 31.25 cm
0.10 - 0.15	0.01 %	0.01 %	0.02 %
0.15 - 0.20	0.01	0.02	0.03
0.20 - 0.25	0.00	0.01	0.04
0.25 - 0.30	0.01	0.06	0.08
0.30 - 0.35	0.04	0.13	0.15
0.35 - 0.40	0.12	0.29	0.31
0.40 - 0.45	0.23	0.45	0.47
0.45 - 0.50	0.27	0.49	0.52
0.50 - 0.55	0.23	0.43	0.46
0.55 - 0.60	0.17	0.32	0.37
0.60 - 0.65	0.12	0.25	0.30
0.65 - 0.70	0.10	0.24	0.30
0.70 - 0.75	0.09	0.23	0.31
0.75 - 0.80	0.07	0.20	0.30
$\sum_{0.10}^{0.80}$	1.5 ± 0.7 %	3.1 ± 0.6 %	3.7 ± 0.5 %

ΔE(MeV)	Percent Exposure in Energy Interval ΔE			
	Increase with Increasing Field Size*, Comparing			Due to Scatter in Source Proper
	25 cm x 25 cm and 5 cm x 5 cm	10 cm x 10 cm and 5 cm x 5 cm	25 cm x 25 cm and 10 cm x 10 cm	
0.10 - 0.15	0.02 %	0.01 %	0.01 %	0.03 %
0.15 - 0.20	0.03	0.02	0.01	0.08
0.20 - 0.25	0.05	0.04	0.02	0.25
0.25 - 0.30	0.12	0.09	0.04	0.41
0.30 - 0.35	0.17	0.14	0.04	0.46
0.35 - 0.40	0.25	0.19	0.07	0.41
0.40 - 0.45	0.34	0.25	0.10	0.33
0.45 - 0.50	0.35	0.26	0.11	0.26
0.50 - 0.55	0.31	0.23	0.10	0.20
0.55 - 0.60	0.27	0.19	0.09	0.17
0.60 - 0.65	0.24	0.15	0.09	0.16
0.65 - 0.70	0.24	0.14	0.10	0.15
0.70 - 0.75	0.24	0.14	0.10	0.15
0.75 - 0.80	0.25	0.14	0.12	0.15
$\sum_{0.10}^{0.80}$	2.8 ± 0.6 %	2.0 ± 0.7 %	1.0 ± 0.8 %	3.2 ± 0.6 %

*Percentage referred to the exposure measured for the larger of the two field sizes.

4. References.

[1] Ehrlich, M., Seltzer, S. M., Bielefeld, M., Trombka, J. I., Spectrometry of a ^{60}Co gamma-ray beam used for instrument calibration, Metrologia 12, 169 (1976).

[2] Hubbell, J. H., Photon cross sections, attenuation coefficients, and energy-absorption coefficients from 10 keV to 100 GeV, NSRDS-NBS 29, Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (1969).

[3] See, e.g., Appendix B, ICRU Report 18, Specification of High Activity Gamma-Ray Sources; International Commission on Radiation Units and Measurements, Washington, D.C. (1969).

[4] See, e.g., Trombka, J. I., Schmadebeck, R. L., Nuclear Instr. Methods 62, 253 (1968).

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Exposure spectra at a distance of 1 meter from the NBS vertical-beam ^{60}Co gamma-ray source are presented in tabular form for field sizes of practical interest. Also tabulated are contributions to exposure arising from source housing and collimator, as well as from the source proper.

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